THURSDAY, NOVEMBER 13, 1913.

THE ZEEMAN EFFECT.

Researches in Magneto-Optics. With Special Reference to the Magnetic Resolution of Spectrum Lines. By Prof. P. Zeeman. (Macmillan's Science Monographs.) Pp. xvi+219+viii plates. (London: Macmillan and Co., Ltd., 1913.) Price 6*s*. net..

THIS synthesis of our knowledge in an important and fundamental branch of physics —opened up by our author in 1896, and afterwards cultivated so zealously and fruitfully by many workers, but by himself far in front of all others—will be most welcome to all who wish to keep abreast of the advancing tide of electrical and optical discovery. Prof. Zeeman has paid us the compliment of writing his book in English; and nowhere, perhaps, will he have more attentive readers than here. Though occasional slight differences of idiom betray that the work is not composed in his native language, yet the clearness and directness of statement, and the conciseness of exposition, enable him to cover a large field, so to speak in a single view, in a manner which will make the book a permanent companion of all who are interested in the progress of the marvellous subject which is indissolubly associated with the name of the Professor of Physics of Amsterdam.

In the early days of this research it could scarcely have been anticipated that it would grow almost into a separate science. The present writer well remembers the earliest announcement in this country of the first phase of Prof. Zeeman's discovery, which was contained in a single sentence in NATURE in December, 1896, imbedded in the midst of an abstract of proceedings of the Amsterdam Academy of about a month before; its importance was, however, at once grasped, and the experiment was promptly repeated and verified by Lodge. The idea of a spectrum line being widened by a magnetic field had in fact been thought of; but a rough estimation had shown that if the ions concerned are comparable in mass to atoms, the effect would be far too slight for practical detection. The actual smallness of the inertia of the electron, only 1/1500 of that of the hydrogen atom, which made all the difference in this regard, could not have been anticipated. But when Zeeman's full paper came to hand, it was found to include much more; not only Lorentz's brilliant and decisive test of a magnetic influence, and its verification, viz., the circular polarisations of the edges of the widened spectral line: it also contained the establishment of an actual splitting of each line into sharp components, which had been suggested as possible, though one would imagine scarcely likely, by the special circumstances of Lorentz's simple illustration of a single electron revolving round a centre of force.

This latter very remarkable result, the sharp multiplication of the line instead of a mere general broadening, remains the theoretical crux of the subject, and at the same time is that feature of definiteness which makes and will make the Zeeman phenomenon so effective a probe as regards the inner physical structure of the individual molecules of matter.

The value thus found for the ratio of charge to inertia, for the negative optical electron, fell at once into line with the value belonging to the free corpuscles of J. J. Thomson—the Crookes-Stokes torrent of charged particles which carry the kathode current in vacuum tubes—as announced by the discoverer of free electrons, and of their stupendous translatory velocities, in the earlier part of the same year. Thus the electron theory, which already embraced in its theoretical scope all electric phenomena as well as all effects of radiation, was raised, by convergence from both its aspects in the same year, from a mental constructive synthesis to the rank of tangible experimental fact. Special electron theories could thus in future be launched out in detail, into regions of tentative speculation hitherto almost regarded as fanciful, as the test of experiment became applicable more and more as a check on their exuberance or an indication for their fruitful modification.

The earliest general comparative study of the phenomena of resolution, for the various spectral lines of the same chemical element and of related elements, was made in the two following years by Preston, working within the circle of FitzGerald's influence in Dublin, who was able, as it happened, to turn to account a powerful Rowland grating that had just previously been established at the Royal University. The circumstances which prevented Zeeman himself, for nearly ten years, from proceeding with the full exploration of his own subject in this direction—namely, his transfer from the Leyden laboratory to a lectureship at Amsterdam University, and the very imperfect spectroscopic equipment which he found there—are recorded here not without pathos, at the beginning of chap. iv., in explanation of his occupation during those years mainly on side problems which could be attacked with small optical powers.

The rule announced by Preston, and now appropriately known by his name, as it arose out of his last piece of work before the premature termination of a promising career in science, viz., that in each spectral series the magnetic separations measured in frequency are the same for all lines, and that there is close parallelism for elements of the same chemical group, remains the chief generalisation in this branch of the subject. It was fully confirmed by the much more extensive investigations of Runge and Paschen published three years later. But in fact the narrower foundation on which Preston built may well have appeared at the time to be sufficient, in view of the pertinent theoretical considerations.

The fundamental puzzle, why there should be definite resolution at all, instead of hazy broadening, has already been referred to. The most general theoretical system for which definite resolution can be predicted remains now, as then, one composed of any number of negative electrons describing orbits, however entangled, under their mutual repulsions in a field of force steady (or nearly steady), thus due to positive charges fixed (or nearly fixed, as they may well be, even though free, on account of attached inertia), and symmetrical with respect to the axis of the impressed magnetic field. In such a case the effect of an impressed magnetic field H on the system is the same as that of an impressed rotation round the axis of the field with velocity $\omega = eH/2m$; and in the analysis of the radiation which the system sends out, all its spectral lines are therefore divided into normal triplets, *i.e.* according to the elementary Lorentz rule, with the common interval $\omega/2\pi$ in their frequencies. If a natural spectral series had been found to behave differently from this theoretical system, it would at that time have been a matter for surprise: yet in Runge and Paschen's work, though Preston's rule is obeyed, the resolution proved often to be very different from the normal triplet type which is characteristic in the proposition above quoted. Instead, however, these experimenters found order of a more general kind, the components, often more than three, being usually symmetrically spaced at intervals which are equal to or exact sub-multiples of the standard Lorentz amount.

Not a few attempts have been made for the theoretical elucidation of this remarkable rule; but it probably still remains as a touchstone for the next substantial advance in the dynamics of molecular structure. Prof. Zeeman rather hints his opinion that its range of approximate application may be limited, just as the original standard triplet resolution proved to be exact only in special systems. Large accumulations of material exist for detailed comparative study: the subject has in fact now definitely entered the chemical laboratory, and attention is specially directed by our author to the work of J. E. Purvis with Dr. Liveing's spectroscopic equipment at Cambridge, revealing identical types of resolution in the spectra of numerous elements in which series are not as yet known.

For further progress on the physical side, much higher resolving power is a desideratum, which, indeed, is now rapidly being applied. A beginning has been made (by Nagaoka in a recent letter in NATURE, August 25) in the mapping of the remarkable changes of type of resolution of the definite satellites attached to certain lines, as the magnetic field is increased: this phenomenon, and the simplification, in fact fusion, which has been found by Paschen and Back to ensue in the resolution of close multiple lines, when the field becomes very great, and more recently by Fortrat, following early isolated observations by Michelson and others, lend weight to Voigt's hypothesis of some kind of vibrational linkage between adjacent lines, even when their own modes of resolution are of different types.

Such difficulties as these have obstructed the general theory, as approached from the side of the radiation from magnetised flames. But at an early stage Voigt had formulated the problem—and has since developed it in many directions, analytically and experimentally, with his usual mastery—from the point of view of propagation of incident radiation through a magnetised medium, a subject already discussed for transparent media in theories of Faraday's rotation of the plane of polarisation and of the related Kerr effect of reflection. If that type of theory is expressed so as to exhibit the mechanism of selective absorption, by the explicit introduction of terms appropriate to molecules vibrating by resonance and attached to the medium, and also of general damping terms when expedient, a dark narrow band which would be single in the absence of an impressed magnetic field should become resolved into Zeeman components when such a field is included; or at any rate this fact will be a guide to the form of the equations.

Almost simultaneously with this theoretical discussion, the Italian physicists Macaluso and Corbino broke the cognate experimental ground, by the detailed observation of an absorption line under very high dispersion, showing that the known excessive and anomalous refraction at its borders was accompanied by excessive and anomalous magnetic rotation, superposed on the magnetic resolution of the line. Indeed, very soon after Zeeman's first discovery, Righi had put the resolution of the line in evidence in a most effective and beautiful manner, in an absorption experiment, simply by showing that a magnetic field restored visibility of the line when applied to an absorbing vapour between nicols crossed for extinction of the light.

In the theoretical procedure of Voigt the radiating molecule has thus disappeared from the scene, or rather has become latent; the problem proposed is now to represent the effect of the medium in bulk heuristically, as well as may be, by introduction of appropriate new types of terms into the differential equations of propagation, new types which owe their justification, or at any rate their suggestion, to the general physical nature of the interaction of the molecules with the æther in the magnetic field. The aim is thus coordination of phenomena rather than their explanation; and the procedure is specially appropriate to that philosophical view which restricts the sphere of physics to the adequate *formulation* of the relations subsisting between the tangible experimental data. The mode in which the interaction of the vibrating molecules gives rise in a general way to such terms in the equations of propagation, including the relation of reciprocity of the Zeeman to the Faraday effect, had been exhibited by FitzGerald, by means of simple illustrative systems, about the same time. All these converging activities show how ripe for the harvest ideas had become, through the progress of the general theory of absorption and the related anomalous dispersion, first essayed by Young with imperfect means of analysis a century ago, and effectively developed in experiment and theory by Kundt, Maxwell, Rayleigh, Sellmeier, Helmholtz, &c. in more recent days.

Similarly, allusion has been made above to the circumstance that the times had been ripening, before Zeeman's discovery, towards the understanding of the relations of a magnetic field to the vibrations of the molecules which take part in the emission or transmission of radiation. The most remarkable and even precise anticipation of all, and one which by good fortune incited Prof. Zeeman to enter upon his investigation, was an experimental attempt made by Faraday himself, which our author had come to know of, very appropriately, from a reference in a lecture by Clerk Maxwell. Then there was the additional fortunate circumstance that Prof. Lorentz was at hand at Leyden, to bring to bear his exact ideas on the nascent discovery and point out the path for further developments. These are opportunities, seemingly merely born of concurrent chances, yet such as are only grasped by men worthy of them. The skill in optical experimentation, which is revealed by the investigations recorded in this treatise, connotes a long training for the tasks there undertaken: we are thus reminded of Prof. Zeeman's early exact measurements on the Kerr effect in reflection of light from a magnetic pole (not mentioned in this book), by which he won his spurs at Leyden, doubtless in that problem also enjoying the stimulus of Lorentz's advice and inspiration.

Recently the centre of interest has shifted in this subject into a purely observational side, to the mountain peak in California where G. E. Hale and his associates, by refined and determined work with the very powerful special equipment of the Carnegie Observatory, have realised in marvellous ways, still awaiting closer interpretation, one of Zeeman's anticipations in his earliest paper, the application of the method to the exploration of the magnetic phenomena of the sun, greatly expanding thereby our picture of the activities of the ultimate source of all our light and power.

But we must stop: these topics, and many others of absorbing and often perplexing interest, may be followed up in the book itself. Less than twenty years ago the Zeeman effect was unknown, we may almost say unthought of. Already it permeates, as a method of coordination and discovery, all the most refined problems of electrical and optical science. We have now a handbook of the present state of the subject, of the right degree of detail, written from the experimental point of view without undue occupation or distraction with theoretical speculations for which it yet arranges the material, with brief side expositions recalling to mind succinctly such knowledge of related subjects, spectral resolving power, spectral series, &c., as is essential to the argument: and this reasoned survey has come to us from the hands of the discoverer and chief experimental promoter of the Zeeman phenomenon.

J. L.

P.S.—In the foregoing review of Prof. Zeeman's monograph, which was written early in October, it is remarked that recent observations, especially by Paschen and Back, and afterwards by Fortrat, on the modification of the Zeeman effect in strong fields, give support to the theory advanced by Voigt, which postulates mutual influence between the constituents of a close multiple line in the spectrum. The case may now (November 4) be put stronger. The recent account by Fortrat of the magnetic resolution of a sodium doublet (*Comptes rendus,* October 20, 1913, p. 635) seems to leave no room for doubt that the equations advanced by Prof. Voigt are of the essence of the matter.—J. L.